NBS TECHNICAL NOTE 875

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Interlaboratory Intercomparisons of Radioactivity Measurements Using National Bureau of Standards Mixed Radionuclide Test Solutions

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Interlaboratory Intercomparisons of Radioactivity Measurements Using National Bureau of Standards Mixed Radionuclide Test Solutions

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INTERLABORATORY INTERCOMPARISONS OF RADIOACTIVITY MEASUREMENTS USING NATIONAL BUREAU OF STANDARDS MIXED RADIONUCLIDE TEST SOLUTIONS

B. M. Coursey, J. R. Noyce and J.M.R. Hutchinson*

In 1973 the National Bureau of Standards (NBS) distributed three calibrated test solutions to interested laboratories. Two of these solutions each contained nine gamma-ray-emitting radionuclides that the participants were asked to identify and quantify. The third solution contained ^{89}Sr and ^{90}Sr-^{90}Y, and participants were asked to perform a quantitative radioactivity analysis of the mixture. The results reported by all of the participating laboratories are given here. Most of the activity values reported for the mixed gamma-ray-emitting solutions were within ±20 percent of the corresponding NBS values, but less than half of the laboratories reported ^{89}Sr and ^{90}Sr-^{90}Y activity values both of which were within ±20 percent of the NBS values.

Key words: Environment; intercalibration; intercomparison; radioactivity; radionuclide; radiostrontium.

This report is divided into two main parts, the first describing the intercomparison of the two gamma-ray-emitting test solutions, and the second describing the strontium-yttrium radioactivity test solution intercomparison. A final section summarizes the findings of both intercomparisons.

I. Intercomparisons of Mixed Gamma-Ray-Emitting Test Solutions

Introduction

In 1972 the National Bureau of Standards (NBS) began distributing mixed radionuclide gamma-ray emission-rate Standard Reference Materials [1][1] (SRM's). These standards have proven quite useful for calibrating Ge(Li) detector systems used in the analysis of environmental radioactivity.

In January 1973 NBS distributed 60 mixed radionuclide test sources as unknowns through the Standard Reference Material Program. The two objectives of this distribution were (1) to provide the participants with an opportunity to test their measurement techniques using an unknown sample containing nine radionuclides which give rise to 31 gamma-ray lines, and (2) to allow NBS to evaluate the measurement capabilities of a cross section of users of gamma-ray-emitting radioactivity standards. After reporting results to NBS, the users were provided with an SRM certificate (Appendix I).

The fourteen laboratories listed in Table 1 reported results for a total of 19 sources.

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[1] Figures in brackets indicate the literature references at the end of the paper.

* Radioactivity Section, Center for Radiation Research, National Bureau of Standards, Washington, D. C. 20234

Table 1

List of Participants, Mixed Gamma-Ray Test Solution[a]

1. Allied Chemical Company, Idaho Falls, ID
2. Armed Forces Radiobiology Research Institute, Bethesda, MD
3. Atlantic Richfield Hanford Company, Richland, WA
4. Duke Power Company, Charlotte, NC
5. General Electric Midwest Fuel Recovery Plant, Morris, IL
6. Industrial Bio-Test Laboratories, Inc., Northbrook, IL
7. Maine Yankee Atomic Power Company, Wiscasset, ME
8. Millstone Point Company, Waterford, CT
9. Oak Ridge Associated Universities, Training Division, Oak Ridge, TN
10. Ontario-Hydro, Pickering Operations, Pickering, Ontario, Canada
11. Rochester Gas and Electric Corporation, Rochester, NY
12. State of Florida, Division of Health, Orlando, FL
13. Teledyne Isotopes, Westwood, NJ
14. Westinghouse Advanced Reactors Division, Madison, PA

[a]The order in which participants are listed in this table does not correspond to the order in which results are listed in Tables 2 and 3.

Experimental Details

The sources consisted of chromium-51, manganese-54, cobalt-58, iron-59, cobalt-60, zinc-65, cesium-134, cesium-137-barium-137m, and cerium-144-praseodymium-144 in a solution of approximately 4 N HCl. The solution also contained approximately 15 μg of stable cation carrier per gram of solution for each of the radionuclides listed above.

The solutions were distributed in flame-sealed borosilicate-glass bottles of standard dimensions.[1] The larger of the two sources, SRM-4252, was contained in a 450-ml cylinder, which was fabricated from standard borosilicate-glass tubing (75-mm O.D.). The bottom of the bottle was a 5-mm plate-glass disk. Forty such sources were prepared within a mass range of 478.5 - 480.0 g.

The smaller of the two sources, SRM-4253, was a 50-ml cylindrical source, with an outer diameter of 38 mm and a bottom thickness of 3 mm. The forty small sources prepared were within a mass range of 53.4 to 53.7 g. The mass of solution for each SRM-4253 was given on the certificate to the nearest 0.01 g.

The 450-ml source was designed to simulate reactor waste water. For a typical source the ^{60}Co activity in January 1973 was 4.5×10^{-4} μCi/ml. For the 50-ml source, which simulates reactor primary coolant, the ^{60}Co activity was about 8.2×10^{-3} μCi/ml.

The solutions were counted by each participant in the standard-dimension bottles or, usually, transferred to a container of his choice. Two laboratories used NaI(Tl) detectors, while the others used Ge(Li) detectors. It might be noted that laboratory E had a NaI(Tl)-shielded, Ge(Li) detector system.

Results

A reporting form and questionnaire were provided with each source. In most instances, the activities or activities per gram of solution were reported as of the measurement date. The reported values for each radionuclide were divided by the NBS values, corrected for decay, to obtain X/NBS. Values for these ratios are given in Tables 2 and 3 for SRM-4252 and SRM-4253, respectively. Note that the fourteen laboratories were assigned code letters from A to N. Single and double letters are used to denote 450- and 50-ml sources, respectively.

The results for the individual radionuclides are also shown in Figures 1 - 3. Each laboratory reported separately random errors at the 99 percent confidence level and estimated upper limits for systematic errors. We have used the linear sum of their reported random and systematic errors in calculating their uncertainty for the ratio X/NBS. Their uncertainties are represented as error bars on the plotted points in Figures 1 - 3.

Discussion

Two of the laboratories, I and L, used NaI(Tl) detector systems. Their results are of particular interest because of the large number of laboratories which still use such systems for environmental analyses. In Tables 2 and 3 it can be seen that both laboratories failed to identify ^{51}Cr, ^{58}Co, ^{65}Zn, ^{134}Cs, and ^{144}Ce in the mixture. The reported value for ^{54}Mn by laboratory L may include contributions from the ^{58}Co photopeak at 810 keV and the ^{134}Cs photopeaks at 796 and 802 keV.

Of the other 12 laboratories, all of which used Ge(Li) detectors, laboratory A evidently had a calibration problem at the time of this test. For the large source their values were systematically about 25% higher than the NBS values, while for the 50-ml source (AA) they reported only one-half of the NBS value. Their reported values for ^{51}Cr were high for both sources.

TABLE 2

RESULTS FOR NBS MIXED RADIONUCLIDE RADIOACTIVITY TEST SOURCE

SRM-4252 (450 ml)

Values Reported are X/NBS

Laboratory / Measurement Date / Radionuclide	A 1-19-73	C 2-7-73	E 2-14-73	G 2-17-73	I 2-23-73	K 3-18-73	M 5-7-73
Chromium-51	9.554	1.071	1.084	1.044	a	1.123	a
Manganese-54	1.344	1.124	0.961	1.045	b	1.020	1.146
Cobalt-58	1.266	1.070	1.183	0.952	a	1.010	1.136
Iron-59	1.262	1.066	0.976	1.036	b	1.020	1.207
Cobalt-60	1.181	1.050	0.948	1.057	b	0.936	1.122
Zinc-65	1.354	1.139	0.971	1.137	a	1.012	1.229
Cesium-134	1.625	1.040	1.015	0.999	a	0.883	1.214
Cesium-137	1.169	1.120	0.941	1.002	b	0.952	1.165
Cerium-144	a	1.258	0.980	0.968	a	0.922	1.359

[a] Not Reported

[b] Detected but not analysed

TABLE 3

RESULTS FOR NBS MIXED RADIONUCLIDE RADIOACTIVITY TEST SOURCE

SRM-4253 (50 ml)

Values given in the table are X/NBS

Laboratory / Measurement Date / Radionuclide	AA 1-29-73	BB 2-1-73	CC 2-7-73	DD 2-12-73	EE 2-14-73	FF 2-14-73	HH 2-22-73	JJ 3-3-73	KK 3-18-73	LL 4-10-73	MM 5-13-73	NN 8-17-73
Chromium-51	2.439	a	0.953	a	1.008	a	1.167	1.089	1.035	a	a	a
Manganese-54	0.694	1.019	1.105	0.930	0.943	0.969	0.996	1.123	1.093	1.814	1.072	0.927
Cobalt-58	0.579	0.936	1.028	0.963	1.153	0.961	0.953	1.060	1.096	a	1.034	0.853
Iron-59	0.581	1.116	1.024	1.040	0.947	0.953	0.946	1.046	1.136	b	1.214	a
Cobalt-60	0.513	1.149	1.002	0.960	0.945	0.977	0.998	1.132	0.988	1.084	1.079	0.894
Zinc-65	0.514	1.375	1.112	1.061	0.955	1.041	1.083	1.229	1.140	a	1.124	0.928
Cesium-134	0.490	1.017	0.944	1.039	1.048	1.055	0.936	0.957	0.968	a	1.085	0.877
Cesium-137	0.566	1.008	1.086	0.947	0.920	0.992	0.996	1.120	1.034	0.721	1.074	0.896
Cerium-144	a	0.804	1.170	0.899	0.964	0.959	0.970	1.359	0.956	a	1.129	0.865

[a] Not reported

[b] Detected but not analysed

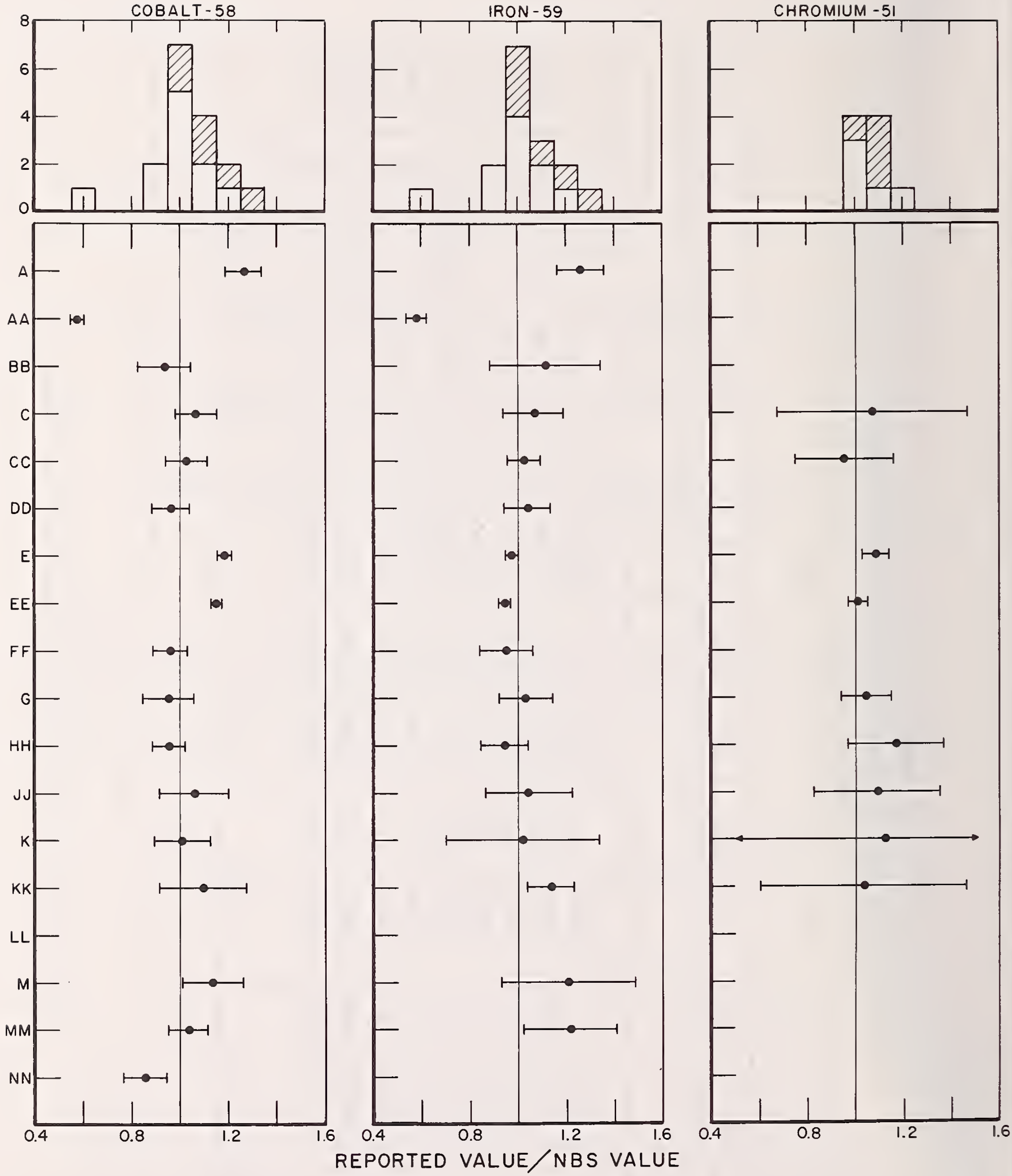

Figure 1. Reported results for SRM-4252 and SRM-4253: Cobalt-58, Iron-59, Chromium-51.

Outliers not plotted: ^{51}Cr Laboratory A (X/NBS=9.554)

^{51}Cr Laboratory AA (X/NBS=2.439)

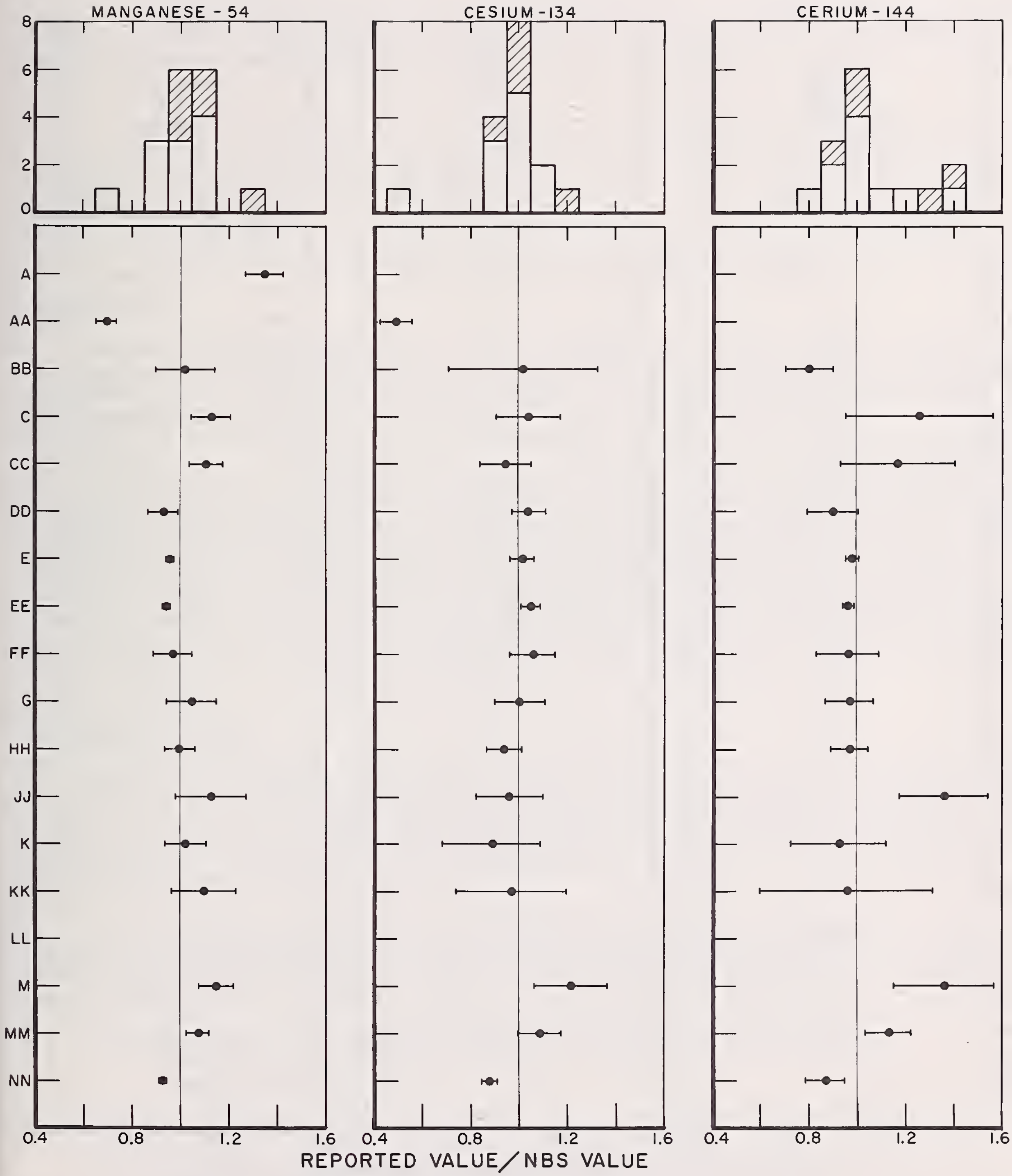

Figure 2. Reported results for SRM-4252 and SRM-4253: Manganese-54, Cesium-134, Cerium-144.

Outliers not plotted: ^{134}Cs Laboratory A (X/NBS=1.625)

^{54}Mn Laboratory LL (X/NBS=1.814)

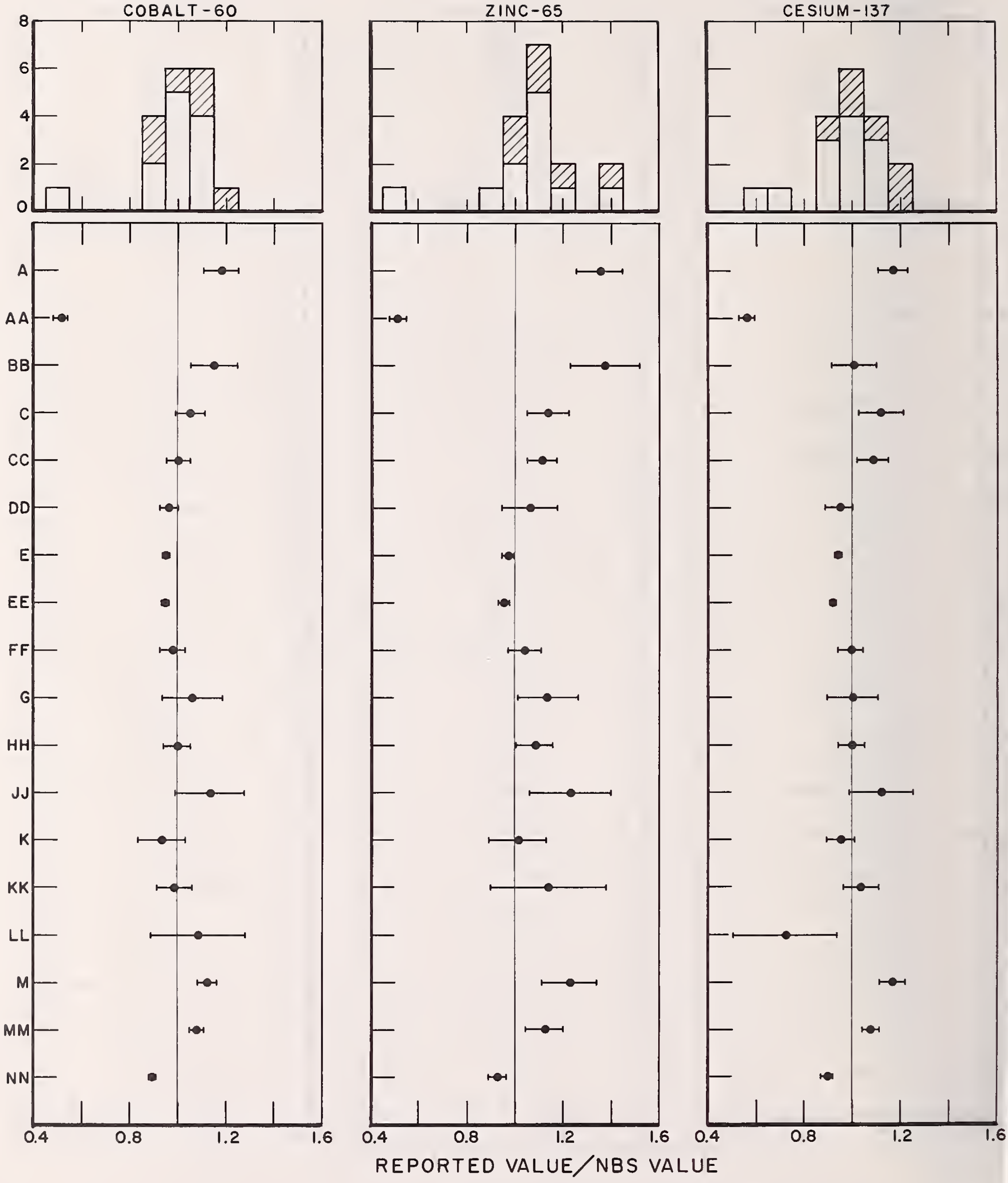

Figure 3. Reported results for SRM-4252 and SRM-4253: Cobalt-60, Zinc-65, Cesium-137.

As is evident from Figures 1-3, the results reported by most laboratories are fairly evenly distributed around the NBS value (i.e., X/NBS = 1). The shaded and unshaded blocks on the histograms represent results for the 450- and 50-ml sources, respectively. The laboratories appear to have measured the 50 ml and 450 ml sources about equally well.

In Figure 3 it can be seen, however, that most of the reported values for zinc-65 are high. The zinc-65 photopeak at 1115.5 keV falls on the Compton edge of the cobalt-60 1333-keV gamma-ray. Therefore, for this mixture, errors in Compton background subtraction may be relatively large.

II. Intercomparison of Strontium-89, Strontium-90-Yttrium-90 Radioactivity Test Solution

Introduction

Because of the long half life of ^{90}Sr, and because it is a bone seeker, maximum permissible radioactive concentrations of this nuclide in air and water[2] are low compared to those of most fission and activation products. The principal difficulties encountered in radiostrontium analyses are (1) ^{90}Sr and ^{90}Y are pure beta-particle emitters, and (2) ^{89}Sr, an essentially pure beta-particle emitter, is also often present in the samples.

Over the years, the Radioactivity Section of NBS has produced solution standards of ^{89}Sr and of ^{90}Sr-^{90}Y for calibration of detectors and testing of radiochemical procedures. In November 1973 the Section made available a test solution containing a mixture of these standards in order to help environmental radioactivity monitoring laboratories evaluate their radiostrontium analysis capabilities. Twenty-six organizations that included Federal, State, industrial and educational institution laboratories purchased 30 ampoules, and 15 purchasers returned results in a test report form. These laboratories were then sent a Report of Calibration and a letter that stated the ratios of their activity values to the NBS values as of the date of calibration. The participants are listed alphabetically in Table 4.

Experimental Details

The test solution was prepared by mixing calibrated solutions of ^{89}Sr (SRM 4945-C) and ^{90}Sr-^{90}Y (SRM 4919-C). The initial activity of each radionuclide was chosen to simulate that often found in the primary coolant of water-cooled nuclear-power reactors. The certified values for the radionuclide concentrations in the test solution and their uncertainties are given in the Report of Calibration (Appendix II) along with impurity and half-life information.

Each participant analyzed the test solution by the method(s) of his choice. In general, the methods used by any one laboratory were not necessarily the same as those employed by other laboratories. However, the analytical methods used can be grouped into three categories. These and the number of participants using each are as follows:

(a) Counting only the strontium activities after an initial separation from ^{90}Y and precipitation with a strontium carrier, and recounting after ingrowth of ^{90}Y (4);

(b) Liquid-scintillation counting and Cerenkov radiation counting (2);

(c) Separation of strontium and yttrium activities, and counting each after precipitations of strontium and yttrium carriers (9).

There were variations within each category, especially the last where several different separation steps were utilized and several different precipitates were made.

Table 4

Participants in the Intercomparison of the ^{89}Sr, ^{90}Sr-^{90}Y Test Solution

The order in this table is different from that in Table 5.

1. Atomic Energy of Canada Limited, Commercial Products, Ottawa, Ontario.
2. Baltimore Gas and Electric Company, Calvert Cliffs Nuclear Power Plant, Lusby, MD.
3. E. I. DuPont de Nemours and Company, Savannah River Plant, Aiken, SC.
4. Emory University, Department of Physics, Atlanta, GA.
5. Florida Power and Light Company, Turkey Point Plant, Miami, FL.
6. General Electric Company, Vallecitos Nuclear Center, Pleasanton, CA.
7. Industrial Bio-Test Laboratories, Inc., Northbrook, IL.
8. Michigan Department of Public Health, Division of Radiological Health, Lansing, MI.
9. New York State Department of Health, Radiological Sciences Laboratory, Albany, NY.
10. Northern States Power Company, Monticello Nuclear Generating Plant, Monticello, MN.
11. NUS Corporation, Radiological Monitoring Programs, Rockville, MD.
12. State of Florida, Division of Health, Radiological Health Unit, Orlando, FL.
13. United States Atomic Energy Commission, Health Services Laboratory, Idaho Falls, ID.
14. United States Environmental Protection Agency, National Environmental Research Center, Las Vegas, NV.
15. United States Geological Survey, Denver Analytical Services Unit, Lakewood, CO.

The results of each participant were returned to NBS on a test report form that also asked for information about the counting system and the radiochemical, counting and data reduction procedures used in the analyses.

Results

The results reported by the 15 participants are given in Table 5 and Figure 4 as ratios of the participants' reported values of activity, corrected for decay to the date of calibration, to the NBS calibrated activity value, for ^{89}Sr and for ^{90}Sr plus ^{90}Y. These ratios are denoted as $(X/NBS)_{89}$ and $(X/NBS)_{90}$ respectively. Those laboratories that used NBS radioactivity SRM's or radioactivity standards traceable to NBS to calibrate their detectors have their code letters underlined. For each X/NBS ratio, Figure 4 shows the random counting error at the 99 percent confidence level (inner bars), and the random error plus the linear sum of the estimated upper limits of systematic errors (outer, larger bars).

Discussion

The X/NBS activity ratios have a range from 0.251 to 1.543 for ^{89}Sr, and from 0.458 to 1.992 for ^{90}Sr plus ^{90}Y. The deviations of several of the ratios from unity are greater than the reported total uncertainties (Figure 4), and may be indicative of unsuspected systematic error in the analytical procedures of these laboratories. The distributions are not greatly skewed, the averages being 0.928 and 1.031, and the medians being 0.95 and 0.98 for $(X/NBS)_{89}$ and $(X/NBS)_{90}$ respectively.

The agreement of the reported activity values with the calibrated values does not appear to be strongly influenced by the analytical method used or when the analysis was performed. Of the two results obtained by using an analytical method in category (b) one was in good agreement with the NBS value, the other was not. In general, activity values for ^{89}Sr acquired by an analytical method in category (c) were closer to the NBS value than those obtained through methods in category (a). It should be pointed out, however, that only four laboratories used an analytical method in category (a). Participants who performed their analyses within a few months after the date of calibration tended to have results for ^{89}Sr that were more consistent with the NBS value than those with later dates of analysis. There are no obvious reasons, however, for such correlations.

The seven participants who stated that they had used NBS radioactivity SRM's or other radioactivity standards that are traceable to NBS to calibrate their detectors, reported, as a group, values in better agreement with NBS for ^{90}Sr-^{90}Y than those who did not. Use of such standards apparently did not significantly help the participants with their ^{89}Sr measurements.

The reported uncertainties varied greatly both in magnitude and in the relative contributions of the estimated random and systematic errors to the total uncertainties. It is clear, from Figure 4, that there is no obvious correlation between estimated errors and agreement with the NBS value. The uncertainties reported for the ^{89}Sr activity values tended to increase as the time between the date of calibration and the date of analysis increased, probably because of the decay of ^{89}Sr.

Summary

A total of 14 laboratories, representing power reactors, industry, state health organization and environmental consultant groups tested their measurement techniques on samples containing a mixture of nine gamma-ray-emitting activation and fission products. Seventy-nine percent and 85 percent of the reported results for SRM 4252 and for SRM 4253, respectively, fell within ±20 percent of the corresponding NBS values.

TABLE 5

Results of Interlaboratory Intercomparison of

^{89}Sr, ^{90}Sr-^{90}Y Radioactivity Test Source

Laboratory F did not report ^{89}Sr

Laboratory Code Letter	Date of Analysis	$(X/NBS)_{89}$ at date of NBS calibration	$(X/NBS)_{90}$ at date of NBS calibration
A	11-28-73	0.743	0.849
B	1-11-74	0.986	1.142
C	2-6-74	0.997	1.008
D	2-1-74	1.249	1.308
E	1-1-74	0.974	1.088
F	4-18-74	---	0.526
G	7-9-74	1.543	0.908
H	4-25-74	0.995	0.940
I	12-6-73	0.629	0.458
J	2-15-74	0.813	1.992
K	7-25-74	1.230	1.163
L	8-2-74	0.930	0.827
M	7-17-74	0.835	0.982
N	9-5-74	0.251	1.327
O	9-24-74	0.822	0.953
Average		0.928	1.031
Median		0.95	0.98

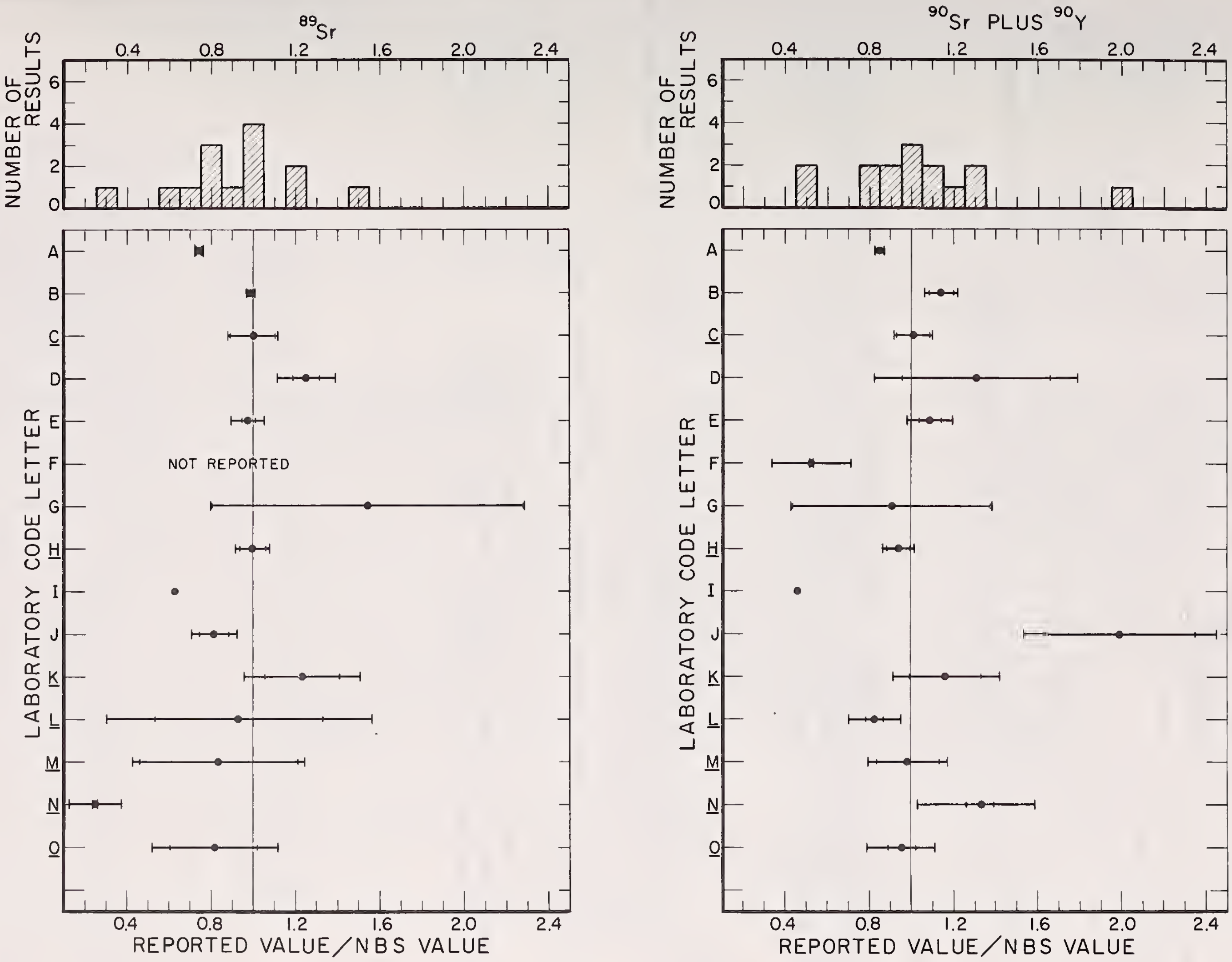

Figure 4. Reported results for the ^{89}Sr, ^{90}Sr-^{90}Y radioactivity test solution. The participants in this intercomparison are listed in Table 4 and are, in general, different from those in the other intercomparison. Inner bars are random errors only; outer, larger bars are total estimated uncertainties (random plus estimated systematic errors).

Seven of the 15 laboratories that participated in the ^{89}Sr, ^{90}Sr-^{90}Y test solution intercomparison reported pairs of activity values with both values within ±20 percent of the NBS calibrated values; nine reported pairs with both values within ±25 percent. Of all activity values reported, 62 percent were within ±20 percent of the NBS values.

It should be noted that the test solutions used in these intercomparisons contained stabilizing carriers in acid media and no interfering chemical species. The accuracies obtainable in routine analyses of radioactivity in environmental samples are not likely to be better than the agreements of the reported values in this intercomparison with the NBS values. The conclusions reached by Fukai *et al.*[3] in an intercomparison of fission-product activities in sea water also seem applicable to these two intercomparisons. They noted that "only in a few cases was unsatisfactory performance related to the methods used," and "generally, bad results seem to be related to the lack of 'good housekeeping,' especially of stringent attention to calibration of counting equipment."

Acknowledgement

The authors gratefully acknowledge the assistance of Miss L. M. Cavallo in the development of the prototype standards, and Miss P. A. Mullen in the preparation of the test sources. The authors also wish to express their appreciation to Dr. W. B. Mann for many helpful discussions during the development of these standards.

References

1. Cavallo, L. M., Coursey, B. M., Garfinkel, S. B., Hutchinson, J.M.R., Mann, W. B., "Needs for Radioactivity Standards and Measurements in Different Fields", Nucl. Instrum. Methods, 112, 5 (1973).

2. "Standards for Protection Against Radiation," Code of Federal Regulations, Title 10, Ch. 1, Part 20.

3. Fukai, R., Ballestra, S. and Murray, C. N., Proc. IAEA Symp., "Interaction of Radioactive Contaminants with Constituents of the Marine Environment," (Seattle, Washington, 1972), International Atomic Energy Agency, Vienna (1973).

U. S. Department of Commerce
Frederick B. Dent
Secretary

National Bureau of Standards
Richard W. Roberts, Director

Appendix I

National Bureau of Standards
Certificate

Standard Reference Material 4252

Mixed Radionuclide Radioactivity Standard

This standard consists of chromium-51, manganese-54, cobalt-58, iron-59, cobalt-60, zinc-65, cesium-134, cesium-137, and cerium-144 in grams of approximately 4N HCl in a flame-sealed borosilicate glass bottle of standard dimensions. The solution also contains approximately 15 ppm by weight of stable cation carrier for each of the radionuclides listed above.

This standard was made by weighing an aliquot of a calibrated radionuclide mixture into the bottle containing the acid. This calibrated mixture was prepared by mixing standardized solutions of the individual radionuclides.

The cerium-144 was calibrated by gamma-ray intercomparison with material which had previously been standardized by $4\pi\beta$-γ coincidence counting. The radioactivities of the other standardized solutions used were determined by means of the NBS calibrated $4\pi\gamma$-ionization chamber.

The radioactivities of the constituents in nuclear transformations per second at 1200 EST January 15, 1973, are shown in the table below.

Radionuclide	ntps	Uncertainty % Random	Systematic	Total
^{51}Cr	1851	0.1	4.2	4.3
^{54}Mn	3622	0.1	2.5	2.6
^{58}Co	3976	0.1	2.9	3.0
^{59}Fe	3574	0.1	2.6	2.7
^{60}Co	7680	0.1	1.3	1.4
* ^{65}Zn	6788	0.1	2.6	2.7
^{134}Cs	1203	0.1	2.5	2.6
** ^{137}Cs	5384	0.1	2.0	2.1
^{144}Ce	3588	0.7	2.3	3.0

* Assuming a gamma-ray intensity of 50.6 ± 0.4% for the 1.115-MeV gamma ray.

** Assuming a gamma-ray intensity of 85.0 ± 0.3% for the 0.662-MeV gamma ray.

The uncertainties in the radioactivities are the 99-percent-confidence limits for the random error components, and the linear sums of the estimated upper limits of conceivable systematic errors.

This standard contains cobalt-57 as an impurity. The cobalt-57 activity was less than 0.1 percent of the total activity on January 15, 1973. The gamma-ray energy spectrum of the standard was examined with a Ge(Li)-spectrometer, and no other impurity was observed.

This standard was prepared in the NBS Center for Radiation Research, Applied Radiation Division, Radioactivity Section, W. B. Mann, Chief.

Washington, D.C. 20234
January 1973

J. Paul Cali, Chief
Office of Standard Reference Materials

FORM NBS-443
(REV. 12-65)

Appendix II

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF CALIBRATION

STRONTIUM-89, STRONTIUM-90-YTTRIUM-90

Radioactivity Test Solution

This source consists of ^{89}Sr and ^{90}Sr-^{90}Y in approximately 5 grams of solution in a flame-sealed, borosilicate glass ampoule. The solution, in 1 N HCl, contains, per gram, 0.01 mg of stable strontium and 0.011 mg of stable yttrium as carriers.

The ^{89}Sr activity in nuclear transformations per second per gram of solution at 1200 EST on November 1, 1973, was

$$* \; 90.3_6 \pm 3.5\% \; * \; .$$

The ^{89}Sr in this test solution came from NBS Standard Reference Material 4945-C that was calibrated by means of $4\pi\beta$ proportional counting.

The uncertainty in the ^{89}Sr activity, 3.5 percent, is the linear sum of 1.3 percent, which is the 99 percent confidence limit of the $4\pi\beta$ measurements (9.925 S_m, where S_m is the standard error, and 9.925 is the Student t factor for three sets of measurements), and the estimated upper limits of conceivable systematic errors.

The total combined activity of ^{90}Sr and ^{90}Y, in equilibrium, in nuclear transformations per second per gram of solution at 1200 EST on November 1, 1973, was

$$* \; 5.13 \pm 3\% \; * \; .$$

The ^{90}Sr - ^{90}Y in this test solution came from NBS Standard Reference Material 4919-C that was calibrated by means of $4\pi\beta$ proportional counting.

The uncertainty in the ^{90}Sr-^{90}Y activity, 3 percent, is the linear sum of 1.3 percent, which is the 99 percent confidence limit of the $4\pi\beta$ measurements (4.541 S_m, where S_m is the standard error, and 4.541 is the Student t factor for five sets of measurements), and the estimated upper limits of conceivable systematic errors.

The Standard Reference Materials used in preparing this test solution were examined with a Ge(Li) spectrometer system for gamma-ray-emitting impurities, and the ^{89}Sr was found to contain ^{58}Co, ^{65}Zn and ^{85}Sr. The activity ratios, $^{58}Co/^{89}Sr$, $^{65}Zn/^{89}Sr$ and $^{85}Sr/^{89}Sr$, had upper limits of approximately 6×10^{-5}, 4×10^{-4}, and 6×10^{-3}, respectively, as of November 27, 1973.

A half life of 50.60 ± 0.12 days for the ^{89}Sr in this test solution was derived from ten sets of $2\pi\beta$-ionization-chamber measurements made on each of two samples over a period of two months. The uncertainty, 0.25 days, is the 99% confidence limit. A half life of 28.5 ± 0.8 years for ^{90}Sr is suggested; this is the half life adopted by the compilers of the Nuclear Data Tables (Section A, Vol. 8, Nos. 1-2, Oct., 1970).

For the Director,

W. B. Mann, Chief
Radioactivity Section
Center for Radiation Research

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

In 1973 the National Bureau of Standards (NBS) distributed three calibrated test solutions to interested laboratories. Two of these solutions each contained nine gamma-ray-emitting radionuclides that the participants were asked to identify and quantify. The third solution contained ^{89}Sr and ^{90}Sr-^{90}Y, and participants were asked to perform a quantitative radioactivity analysis of the mixture. The results reported by all of the participating laboratories are given here. Most of the activity values reported for the mixed gamma-ray-emitting solutions were within ± 20 percent of the corresponding NBS values, but less than half of the laboratories reported ^{89}Sr and ^{90}Sr-^{90}Y activity values both of which were within ± 20 percent of the NBS values.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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